Broadband Inversion in Shallow Water

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LONG-TERM GOAL

Largely because of the exponential growth in computer technology, we can now embed sophisticated acoustic models in SONAR and ocean-observing systems. We seek to do so in a physics-based sense, with an understanding of what acoustic features can *reliably* be exploited in the signal-processing algorithms.

OBJECTIVES

The specific objectives are to study acoustic propagation in topographically and oceanographically complex areas; to identify robust features in the channel response; and thereby to design robust signal-processing algorithms to both track quiet sources and observe the marine environment.

APPROACH

The experimental component is central to this effort. In the current year, we have been working with data from the tri-national (France-Portugal-US) INTIMATE 96 experiment (Internal Tide Monitoring by Acoustic Tomography Experiment). This experiment was conducted in an area off the coast of Portugal, which provided both strong oceanographic and topographic variability.

A new partner with expertise in SAR imaging (DERA/United Kingdom) has joined the program this year. In April we all met and laid out an ambitious set of 4 experiments called INTIMATE 98. This was conducted this July in the Bay of Biscay off the West Coast of France. By simply going to a different site, we gain a broader view of the behavior of internal tides and their acoustic impact. However, beyond that the experiment was specifically designed to provide a different perspective. In particular, one phase of the experiment involves long-range propagation in deep water while another includes a much more severe topographic variation (100-1000 m). This latter component also involves two well-separated, vertical line arrays and will allow us to look at 3D source-localization and inter-array processing.

WORK COMPLETED

INTIMATE 96 was a great success and provided fascinating experimental data sets. Reports of that work may be found in the reference list. The highlight of that work was the tracking of the towed

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source over an 18 hour period as the tow ship traced out a sort of bow-tie pattern around the vertical array. The source track extended to a range of about 9 km in shallow water and occurred during a period when the internal tides were causing 20-m shifts in the isotherms.

In the current year, my focus has been on a separate phase of INTIMATE 96 in which the ship assumed a 25-hour station in the down-slope direction. As the source is stationary, we can more clearly separate out the effect of the tide itself. Furthermore, this is the direction with the greatest topographic variation so it allows us to 'stress-test' the model-based localization.

RESULTS

A range-depth slice through the environment shows the topographic variation during this phase (Figure 1). The array is located at the left edge and we have shown the ray trace and associated transmission loss for the deepest phone. The results were produced using an enhanced version of the BELLHOP ray-beam model, which is ideal for broadband source tracking in such range-dependent environments. The source was located at about 7-km range from the array.

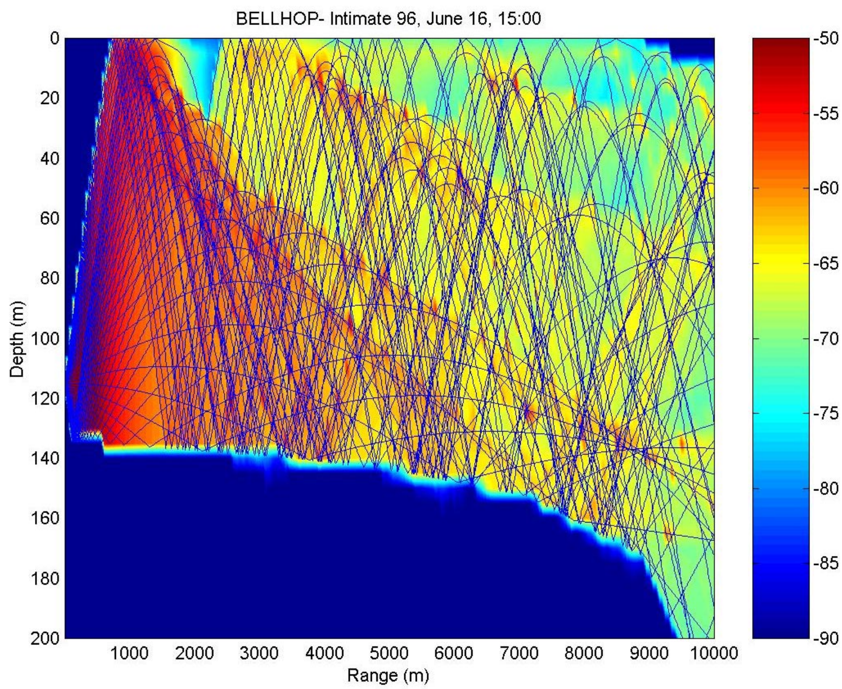

Figure 1 Ray trace and transmission-loss.

The CTD section in Figure 2 shows the signature of the internal tides and we can see that during the period we are processing there is a strong variation with about 20 m variations of the isotherms. This provides a further challenge for the model-based processing.

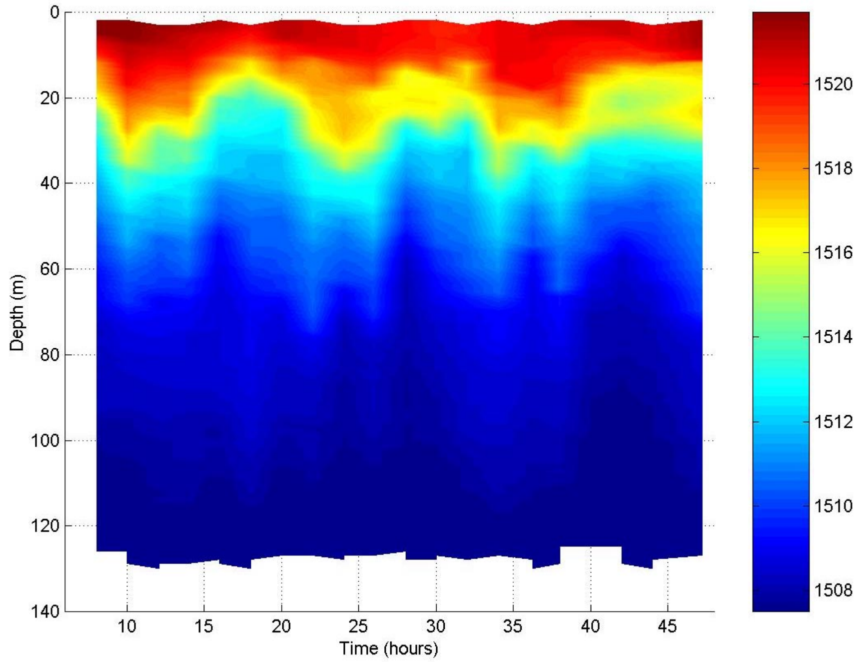

Figure 2 Sound speed profile over time.

To localize the source we do a sort of fingerprint match between the received echo response and an ensemble of suspect echo-responses produced by the BELLHOP model. The model responses are done for source-receiver locations on a 2-D grid in range and depth. With the BELLHOP model, that part of the calculation takes about 10 seconds on a laptop computer.

In theory, the model and data should agree for that source location that corresponds to the one in the experiment. Thus by plotting the similarity of model and data (measured by correlating the time series), we can identify the true source position.

In Figure 3, we have plotted this correlation over a sequence of ranges from 0 to 10 km. In the experiment, pings were transmitted every 8 seconds for 18 hours so that we can observe the source over time. We observe a band that meanders around 7 km on the range-time ambiguity surface. This corresponds to the correct range of the source, verifying the success of the model-based localization. Furthermore, there is a sort of mirage caused by the tides in which the *apparent* source position varies in direct relation to the tides. Recall that the source is in fact stationary during this phase of the experiment.

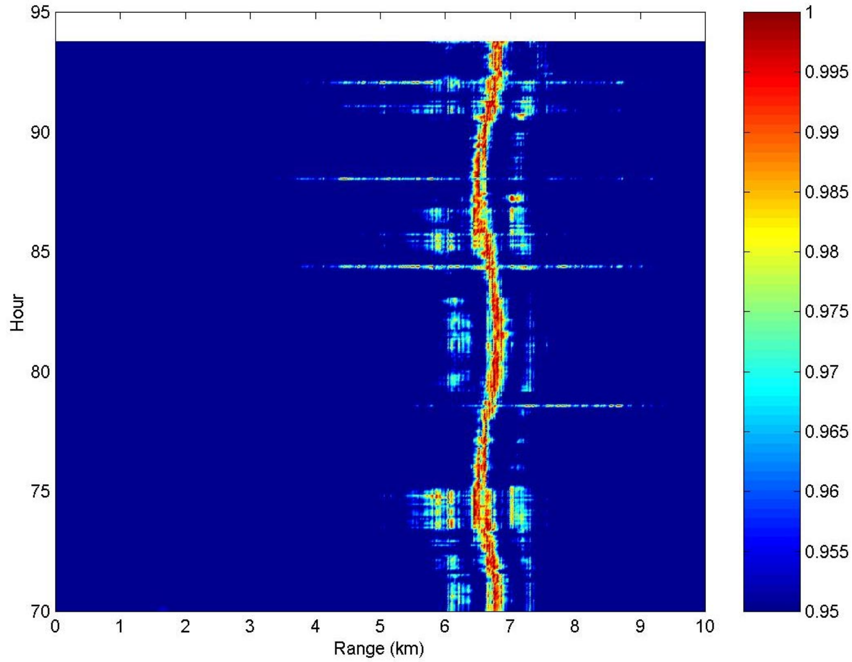

Figure 3 Range-time ambiguity surface.

IMPACT/APPLICATION

The INTIMATE 96 data suggests that shallow-water environments may be much more predicable than had widely been thought. The broadband studies performed here, make clear the source of the variation. This has allowed us to implement a robust approach to source tracking that we hope will have a significant impact on navy SONAR systems. Similarly, the insights about the effects of barotropic and baroclinic oceanographic modes should lead to better tomographic imaging systems.

TRANSITIONS

We have just completed INTIMATE 98, which covers both a larger scale and a new site (Gulf of Gascogne). In addition, I am currently working with NUWC on the multi-line towed array system and hope to transition the resulting algorithms to an operational system.

RELATED PROJECTS

INTIMATE is linked to the PRECOCE (PREdiction du comportement des Couches superficielles de l'Océan le long des Côtes Européenes) project which is designed to develop enhanced upper ocean models for European coastal areas. As mentioned above, the signal processing work is also linked to the NUWC/MLTA program.

PUBLICATIONS

Y. Stephan, X. Demoulin, S. Jesus, E.F. Coelho, and M.B. Porter, “Internal tide impact measured by acoustic tomography experiment," *J. Acoust. Soc. Am.*, Vol. **99**(5), Pt. 2 (1996).

E.F. Coelho, S. Jesus, M.B. Porter, and Y. Stephan “Preliminary acoustic results from the Intimate 96 shallow water tomography experiment" ONR/DARPA Shallow-Water Acoustics Workshop held at NRL October 1–3 (1996).

S.M. Jesus and M.B. Porter, “Shallow water tomography for internal tide estimation: preliminary results of INTIMATE '96" SCNR Meeting, Lisbon, Portugal (1996).

E. Coelho, S. Jesus, M. Porter, Y. Stephan, “One-way active tracking in the INTIMATE 96 Experiment',' *Environmentally Adaptive Sonar Technology symposium,* held at the University of Washington, January (1997).

(team report), "INTIMATE 96 Data report," Service Hydrographique et Océanographique de la Marine TR No. 27 Brest, France (1997).

M. Porter, S. Jesus, Y. Stéphan and X. Démoulin, E. Coelho, “Exploiting reliable features of the ocean channel response”, in *Shallow-water Acoustics*, eds. R.H. Zhang and J.X. Zhou, China Ocean Press (*Proceedings of the International Conference on Shallow Water Acoustics* held in Beijing, China, April 22-25) (1997).

X. Démoulin, Y. Stéphan, S. Jesus, E. Coelho, M. Porter, “INTIMATE96: A shallow water tomography experiment devoted to the study of internal tides”, in *Shallow-water Acoustics*, eds. R.H. Zhang and J.X. Zhou, China Ocean Press (*Proceedings of the International Conference on Shallow Water Acoustics* held in Beijing, China, April 22-25) (1997).

E.F. Coelho, S. Jesus, Y. Stephan, X. Demoulin, and M. B. Porter, “INTIMATE '96: Shallow water tomography in the Sea of the Condemned," *J. Acoust. Soc. Am.*, Vol. **101**(5), Pt. 2 (1997).

Yann Stephan, X. Demoulin, T. Folegot, Sergio Jesus, and Michael Porter, “INTIMATE 96: a shallow water experiment to study internal tides," Geoacoustic Benchmark Workshop, Vancouver, Canada June 24-26 (1997).

M.B. Porter, "Acoustic models as the inner loop: Inverse problems in ocean acoustics, " (invited paper) *Proceedings of the Third International Conference on Theoretical and Computational Acoustics*,. Eds. D. Lee and M. H. Schultz, World Scientific (1997).

O.C. Rodríguez, S. Jesus, Y. Stéphan, X. Démoulin, M. Porter, E. Coelho, “Internal tide acoustic tomography: reliability of the normal modes expansion as a possible basis for solving the inverse problem”, Proceedings of the Fourth European Conference on Underwater Acoustics, Sept. 21-25, Rome, Italy, (1998).

M.B. Porter, S.M. Jesus, Y. Stéphan, E. Coelho, X. Démoulin, (invited) “Single-phone source tracking in a variable environment”, Proceedings of the Fourth European Conference on Underwater Acoustics, Sept. 21-25, Rome, Italy, (1998).

S.M. Jesus, M.B. Porter, Y. Stéphan, E. Coelho, X. Démoulin, “Broadband source localization with a single hydrophone”, Proceedings of Oceans ’98, Sept. 28- Oct. 1, Nice, France (1998).

S.M. Jesus, M.B. Porter, Y. Stéphan, X. Démoulin, O. Rodriguez, and E. Coelho, “Single hydrophone source localization”, submitted to *IEEE J. of Oceanic Engineering*, July (1998).

M.B. Porter, Y. Stephan, S. Jesus, E. Coelho, (invited) "Shallow-water tracking in the Sea of Nazaré," submitted to *IEEE J. Oceanic Engineering* (1998).

Y. Stéphan, X. Démoulin, T. Folegot, S. Jesus, M. Porter, E. Coelho, “Influence de l’environnement sur la propagation acoustique par petits fonds: la campagne de tomographie acoustique INTIMATE96”, Numero 18, EPSHOM/CMO/OCA/NP report, Oct. 12, 1998.

Y. Stéphan, X. Démoulin, T. Folegot, S. Jesus, O. Rodriguez, E. Coelho, M. Porter, “Results of INTIMATE 96”, Proceedings of the INTIMATE 98 meeting March 5-6, Brest, France (1998).

Michael B. Porter, "3-D modeling of the Santa Lucia experiment", Proceedings of the 16th International Congress on Acoustics and the 135th Meeting of the Acoustical Society of America, pp. 2091-2092, 20-26 June 1998, Seattle, USA, Eds. Patricia Kuhl and Lawrence Crum, (1998).

M.B. Porter, Y. Stephan, S. Jesus, E. Coelho, "Shallow-water tracking in the Sea of Nazaré," Proceedings of the 1998 International Symposium on Undersea Technology, April 15-17, Tokyo, Japan, IEEE Catalog Number 98EX101, pp. 29-34 (1998).

M.B. Porter, S. Jesus, Y. Stéphan, S, E. Coelho and X. Démoulin, “Using the echo pattern to range a sound source”, First International Symposium on Physics in Signal and Image Processing, 18-21 January, Paris, France (1999).